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DTRC-PAS-90/17 June 1990

Propulsion and Auxiliary Systems Department

Research & Development Report

A Condition Based Maintenance Monitoring System for Naval Shipboard Machinery

by

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS: None
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): DTRC-PAS-90/17	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: David Taylor Research Center; 6b. OFFICE SYMBOL (If applicable): Code 2758	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Bethesda, MD 20084–5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Office of Naval Technology; 8b. OFFICE SYMBOL (If applicable): ONT 226	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code): Washington, D.C. 22217–5000	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO
62233N	R3360MOR		1–2720–106–1(

11. TITLE (Include Security Classification)

A Condition Based Maintenance Monitoring System for Naval Shipboard Machinery

12. PERSONAL AUTHOR(S)

Christopher P. Nemarich, Wayne W. Boblitt, David W. Harrell

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (YEAR, MONTH, DAY)	15. PAGE COUNT
Technical	FROM 890501 TO 900228	1990 March 6	11

16. SUPPLEMENTARY NOTATION

Presented at the 44th meeting of the Mechanical Failures Prevention Group (MFPG), Apr 2-5, 1990, Virginia Beach, VA

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Automated machine monitoring, Expert systems, Machine health, Condition based maintenance, Fault detection, Process control, Distributed monitoring, Fault diagnosis, Prognosis, Shipboard machinery monitoring

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A demonstration model of a Condition Based Maintenance (CBM) monitoring system has been developed and installed on a high pressure compressor. The CBM model is a distributed, microprocessor-based system incorporating graphical man/machine interface, expert system and local area network software. The CBM model integrates commercially available hardware and software packages with software, sensors and monitoring techniques currently under development. The intent is to apply CBM broadly to naval shipboard machinery for fault detection, diagnosis and prognosis (DD&P). The knowledge gained by implementing increasingly sophisticated systems will be used to develop generic CBM guidelines for naval machinery and ship system designs. This report presents a detailed description of the CBM monitoring system and discusses design issues. This report also presents future development plans for CBM.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Christopher P. Nemarich	22b. TELEPHONE (Include Area Code): (301) 267-2163; 22c. OFFICE SYMBOL: Code 2758

DD FORM 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

0102–LF–014–6602

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ABSTRACT

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INTRODUCTION

One of the roles of the David Taylor Research Center (DTRC) is to conduct research and development in the area of naval shipboard propulsion and auxiliary systems. DTRC also develops sensors and controls for these systems. Because of this expertise, the Logistics Block Program manager tasked the Center to create a technology push in the area of Condition Based Maintenance (CBM) monitoring. The expected benefits of CBM are improved maintenance procedures and scheduling, increased machinery operational readiness, and reduced logistics support cost.

As part of this effort, DTRC has developed a demonstration model of a CBM monitoring system. This demonstration model integrates commercially available hardware and software with developing technologies. The model demonstrates machinery fault detection, diagnosis and prognosis (DD&P) capabilities as applied to naval shipboard systems. The demonstration model makes use of new sensor types, programmable logic control, and industrial process control hardware and software. The model also includes local area networking, graphical man/machine interface and diagnostic software. Expert system software and the results from research in machinery modeling will be used for DD&P.

The near term goals of this program are to successively develop CBM systems for existing machineries and integrate them to form larger systems. The long range goal is to develop generic CBM guidelines for future machinery developments and naval ship system designs.

This paper discusses the CBM demonstration system and some issues involved with the design of naval shipboard monitoring systems.

BACKGROUND

The United States Navy now uses the Planned Maintenance System (PMS) for the upkeep of shipboard system machinery. This involves the periodic overhauling of machinery on a scheduled basis. The operation and maintenance of propulsion and auxiliary systems has steadily become more difficult, costly and labor intensive with the increasing diversity and complexity of these systems. In this era of shrinking maintenance budgets and skilled labor pool, the current means of maintaining and operating Navy ships has come under attack.

Efforts are being made to reduce the number of scheduled overhauls through the periodic monitoring of shipboard machinery health and performance. Data obtained from periodic monitoring helps the ships' forces diagnose machinery problems, determine machinery wear condition, and reduce maintenance procedures. This approach, however, will not solve the Navy's operating and maintenance problems.

The solution is an integrated shipboard machinery monitoring and control system that includes CBM. The Condition Based Maintenance concept encompasses more than just periodic condition monitoring. CBM is an approach that incorporates all aspects of automated machinery failure detection, diagnosis and prognosis. It has been shown by a task group of the Advanced Testing Technology Committee [1] that applying CBM to shipboard hull, mechanical and electrical systems can produce the following benefits:

- reduce maintenance induced failures — 50%
- reduce maintenance actions — 35%
- increase availability — 20%
- reduce inspection and repair hours — 20%
- reduce spare parts provisioning — 20%
- reduce good parts removal — 10%
- extend equipment life/overhaul cycle — 10%

CBM can produce these benefits but it requires an effective resolution of the issues involved with automated shipboard monitoring. The Navy has determined that CBM is an "Imperative Characteristic" [2].

CBM SYSTEM CONCEPT

An established approach is to develop the top-down system concept identifying the pertinent design issues. Once this has been done, the system is implemented from the bottom-up [3]. This is the approach that DTRC is taking.

Some of the issues addressed in the design of the CBM system are the man machine interface, distributed versus centralized processing and data base management, design flexibility and adaptability to shipboard environments.

The overall CBM shipboard system concept developed is shown in Fig. 1. This system has four levels. Level 1 is the programmable logic controllers (PLC). The PLCs reside at the machinery and provide digital machine control and collect and digitize sensor data.

The industrialized PC/ATs at level 2 reside with the PLCs in the machinery spaces. They provide the operator at the graphical man/machine interface with machine control through the PLCs . The operators have access to all information, alarms and control necessary to the operation of their machinery space.

Level 3 is a supervisory level consisting of PC/AT type workstations. These workstations, located in the engineering spaces, contain the historical database for the ship machinery and provide a high level of access to ship engineering system data and control.

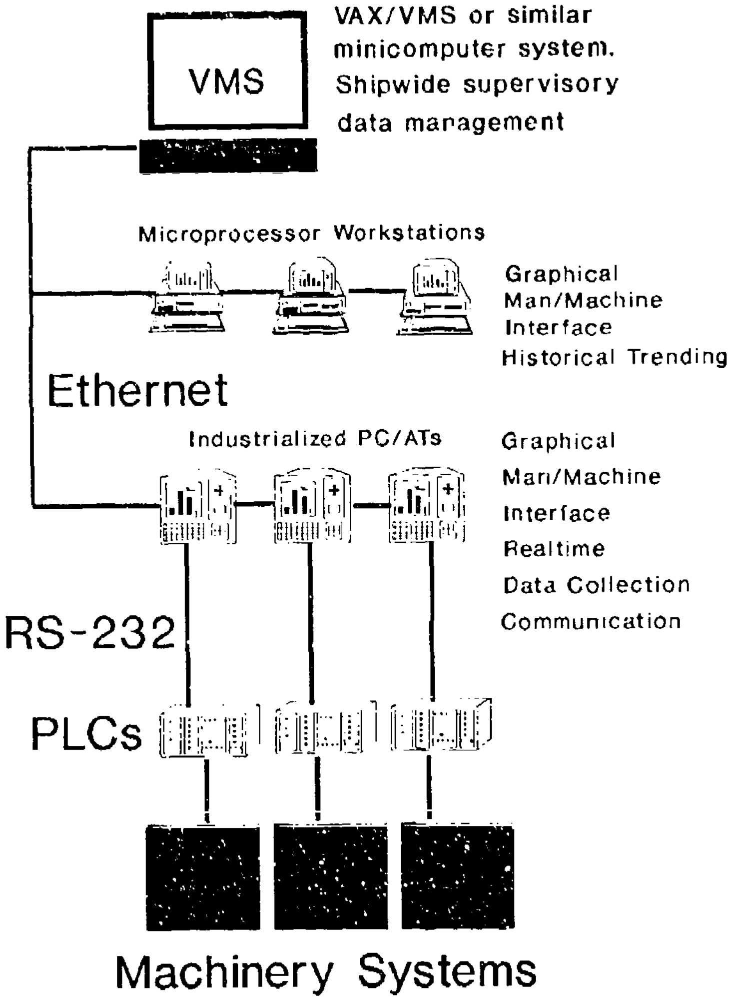

Fig. 1. CBM system concept.

Level 4, the highest level, provides managerial access to each workstation and industrial PC/AT. This level consists of a central VAX/VMS system or equivalent. It performs ship wide data management and control and other tasks required of the ship's most senior officers. Other ship functions would tie into this level.

This is a general system concept. It addresses the issues of distributed control and database management and can be applied easily to a ship environment. It is flexible and is not limited to the technologies listed here. This is the framework from which the CBM system will evolve.

CBM DEMONSTRATION MODEL

A Worthington high pressure air compressor (HPAC) installed in the laboratory provides a means of effectively demonstrating CBM on an actual shipboard auxiliary. The HPAC is a motor-driven, oil-lubricated, water-cooled, four-cylinder air compressor.

Because it is complex and has a variety of subsystems, the HPAC is ideally suited for demonstrating CBM.

The CBM demonstration model is shown in Fig. 2. It consists of a pair of i386 PC/AT computers and a Gould 984 programmable logic controller with 32 channels of A/D. A commercially available process control software package by Intellution, Inc. called FIX/DMACS (TM) is used for the system control, data management, and display. It supports the communication with the PLC, the diagnosis and prognosis software, and the local area network (LAN) software.

The CBM model developed to date works as follows. Analog signals from the HPAC sensor suite are digitized by the A/D modules in the Gould 984 PLC. The HPAC is outfitted with the standard shipboard gages and controls augmented with easily added transducers for data acquisition purposes. In order to aid in the acceptance of the new displays and controls provided by CBM, it is installed alongside the original HPAC gages and meters which have not been removed. The PLC provides limited microprocessor capabilities for data messaging, buffering and control. It communicates with the industrial PC/AT through the IBM realtime coprocessor.

The IBM realtime coprocessor is referred to as an Artic card. The Artic card, via its RS-232 serial port, reads the bank of memory addresses corresponding to the various transducer data channels. It comprises one of the three nodes in the CBM model. The realtime coprocessor executes the SCADA portion of FIX/DMACS software. SCADA is a mnemonic for Scan, Control, Alarm and Data Acquisition. The FIX/DMACS software is installed on both PC/ATs and provides communication between the PCs and the Artic card. This forms a three node FIX/DMACS system.

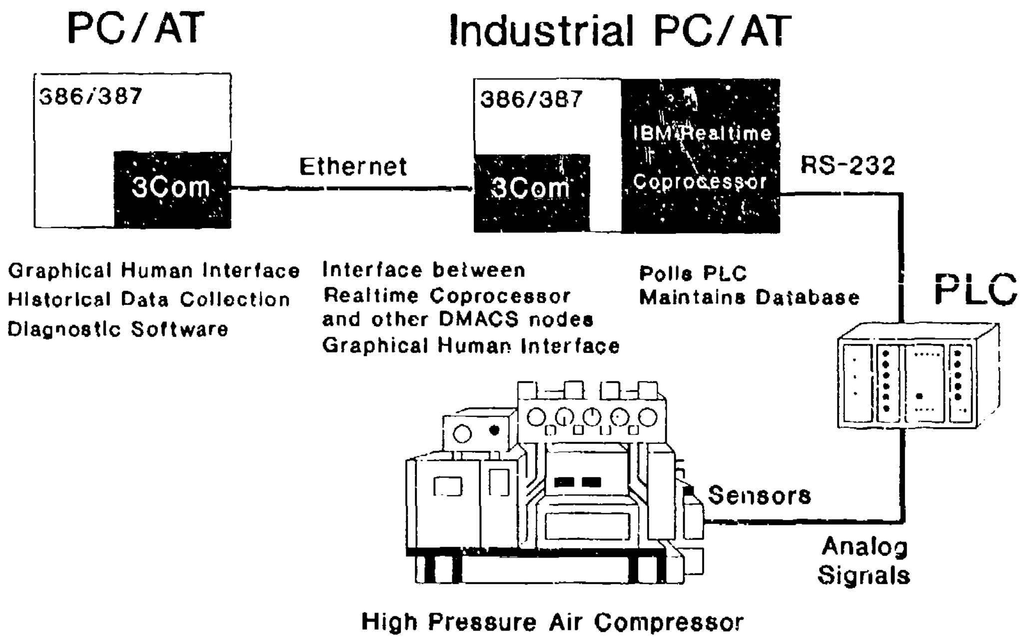

Fig. 2. CBM demonstration model.

HPAC condition information is processed by FIX/DMACS and displayed on the EGA screen for the HPAC operator. This information is also available remotely at the workstation which is in another area of the building. The communication between the PC/AT at the HPAC and the remote workstation is via Ethernet and 3Com hardware.

The remote workstation maintains and stores the HPAC database and provides the operator with access to all information available to the machine operator. Messages can be passed between these nodes.

Ultimately, the workstation will also run a rule-based expert system for the detection, diagnosis and prognosis of HPAC faults. Failure prediction algorithms are being developed for this. At the present time, only C-coded diagnostic rules run at this node.

GRAPHIC MAN/MACHINE INTERFACE

A crucial portion of any automated monitoring system is the man/machine interface. The information flow from machine to man must be dealt with effectively to prevent information overload. Yet it must provide all the necessary data to the system operator. This is one of the central issues to the demonstration CBM system.

A variety of graphic display screens have been designed for CBM. Figures 3, 4, 5, and 6 show the major HPAC system screens. Figure 3 is the ANALOG DISPLAY screen. This screen is the main display and shows the HPAC operator information in an easy to read graphical format. At this screen, air temperatures and pressures for each stage of compression are displayed. The values are displayed relative to their respective alarm and warning states in a bar graph format. A digital screen, not shown, is also available which displays the values of these sensors in a numerical format. The digital screen shows all sensor data including the AC motor speed, current, voltage and power and rate of oil lubrication to the compression cylinders.

If any parameter exceeds either a warning or alarm threshold, the Machine Health box, located in the upper right corner of the display, changes color. Green is normal. Yellow is warning. Red is alarm. The operator can reach any major screen by selecting any of the large boxes at the bottom with the touch screen. The diagnostic box will change color to instruct the operator to go to the diagnostic screen to receive further instructions generated by the expert system.

The AIR SYSTEM screen is shown in Fig. 4. This screen provides a mimic of the HPAC air system. The color of the boxes at each stage of compression represent the condition. Again, the operator can reach any other screen from here.

The OIL SYSTEM screen is shown in Fig. 5. The HPAC oil system consists of a pump for distributing oil to main bearing and crank assembly and an auxiliary oil distribution system for cylinder lubrication. The concept of this screen is similar to the others. This screen, however, incorporates data from a unique fiber optic drop counter sensor. This sensor monitors the rate of drop lubrication to the HPAC cylinders from the auxiliary lube system.

The WATER SYSTEM screen, shown in Fig. 6, displays cooling water inlet temperature and discharge temperature. The pressure at the condensate drain accumulator is also shown.

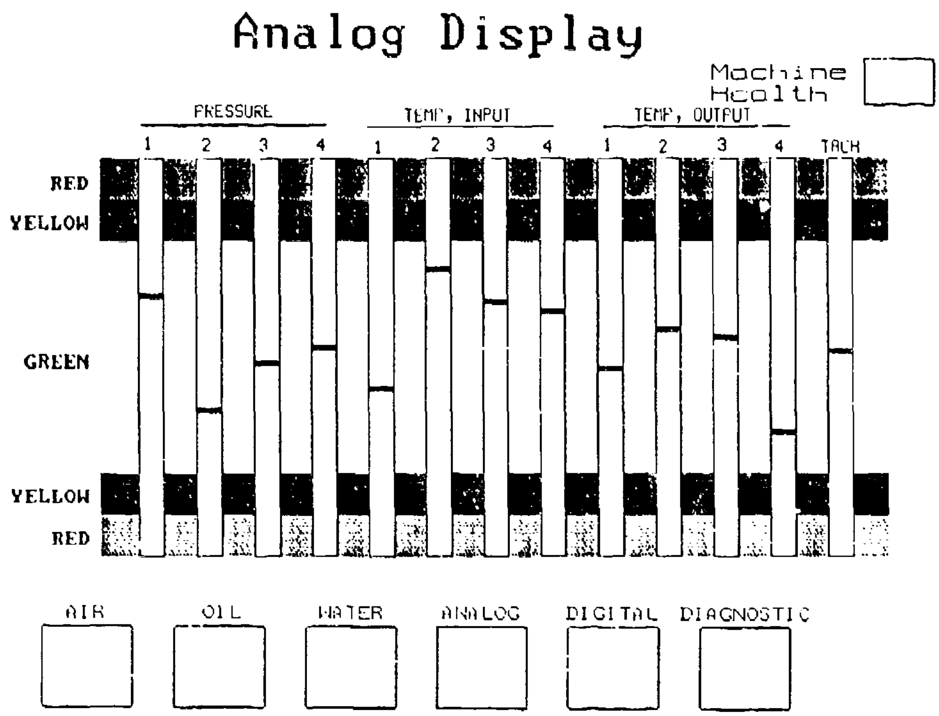

Fig. 3. Analog display screen.

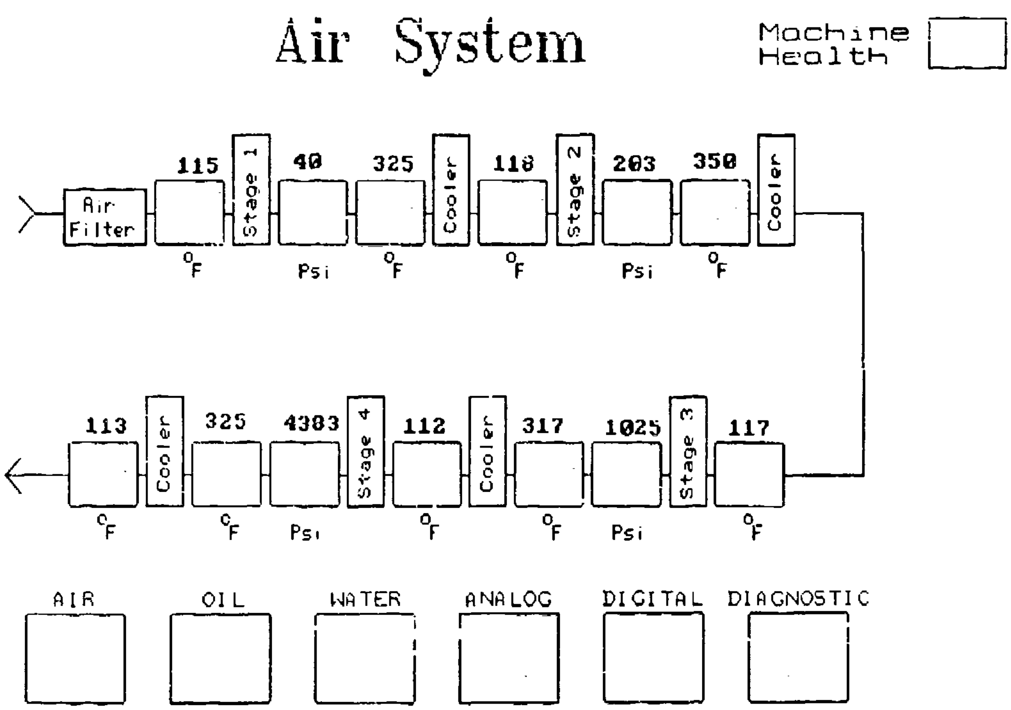

Fig. 4. Air system screen.

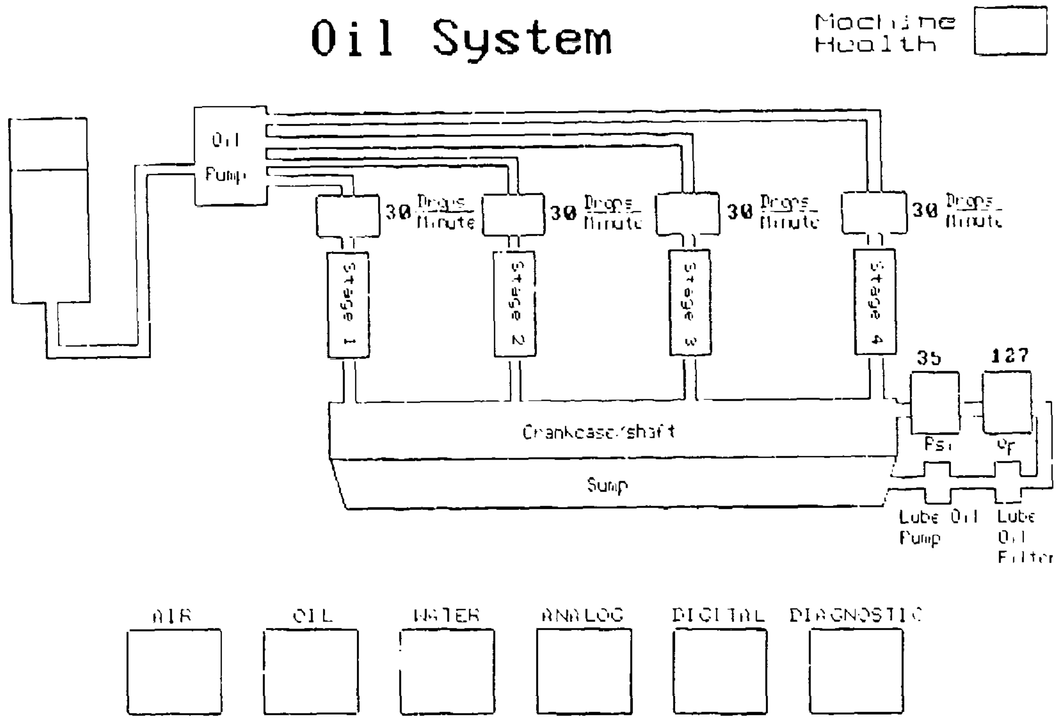

Fig. 5. Oil system screen.

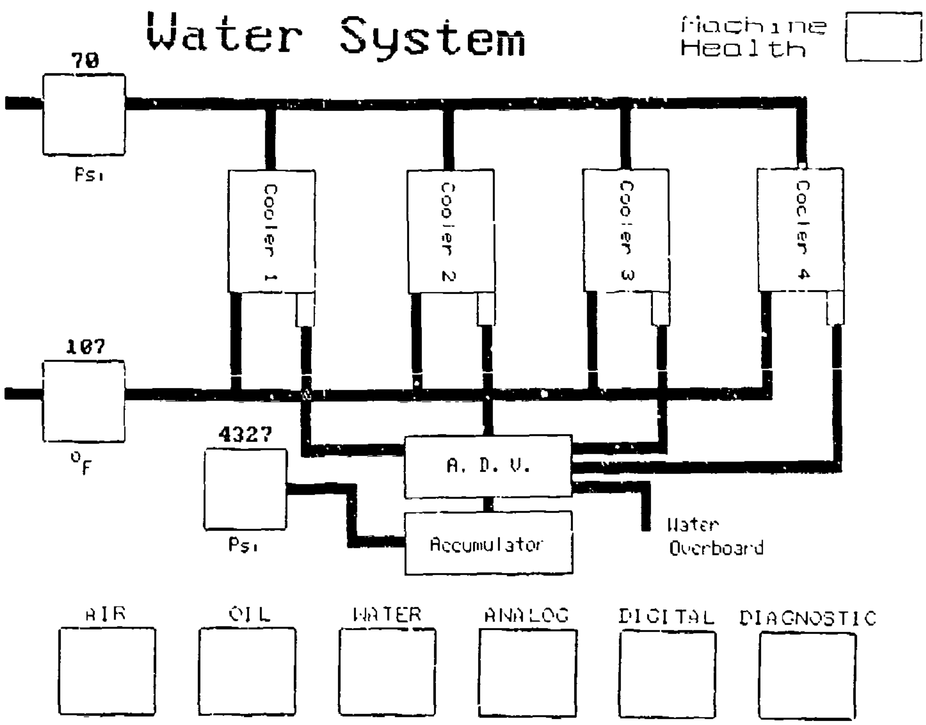

Fig. 6. Water system screen.

From the major screens, a graphical time history of a sensor value may be displayed. The user simply touches the screen element associated with that sensor. The data is displayed as in Fig. 7.

EXPERT SYSTEM DIAGNOSIS

The CBM model is designed to use an expert system software package, NEXPERT (TM), to analyze sensor data and provide a diagnosis of HPAC faults. The intention is for the expert system to obtain sensor data from the SCADA node database. FIX/DMACS provides access to the database via C function calls which are executable on any FIX/DMACS node. With the appropriate knowledge base, NEXPERT can analyze the data and communicate its results back to FIX/DMACS via C function calls.

This plan was postponed because of problems getting FIX/DMACS and NEXPERT to coexist on the same DOS node due to system memory constraints. A temporary solution has been adopted. Diagnostic rules are hard coding within a C program. The C program replaces the expert system with 24 hard coded rules arranged in order of decreasing severity. These rules are developed from the HPAC system manual and equipment experts. Once a rule fires, indicating a fault, a diagnostic number uniquely indicating the fault is immediately sent to FIX/DMACS for display on the screen. The color of the diagnostic box is controlled by this number. A yellow or red diagnostic box indicates the fault severity and directs the operator to the diagnostic screen. Even though more than one fault may be present, only the most severe is reported.

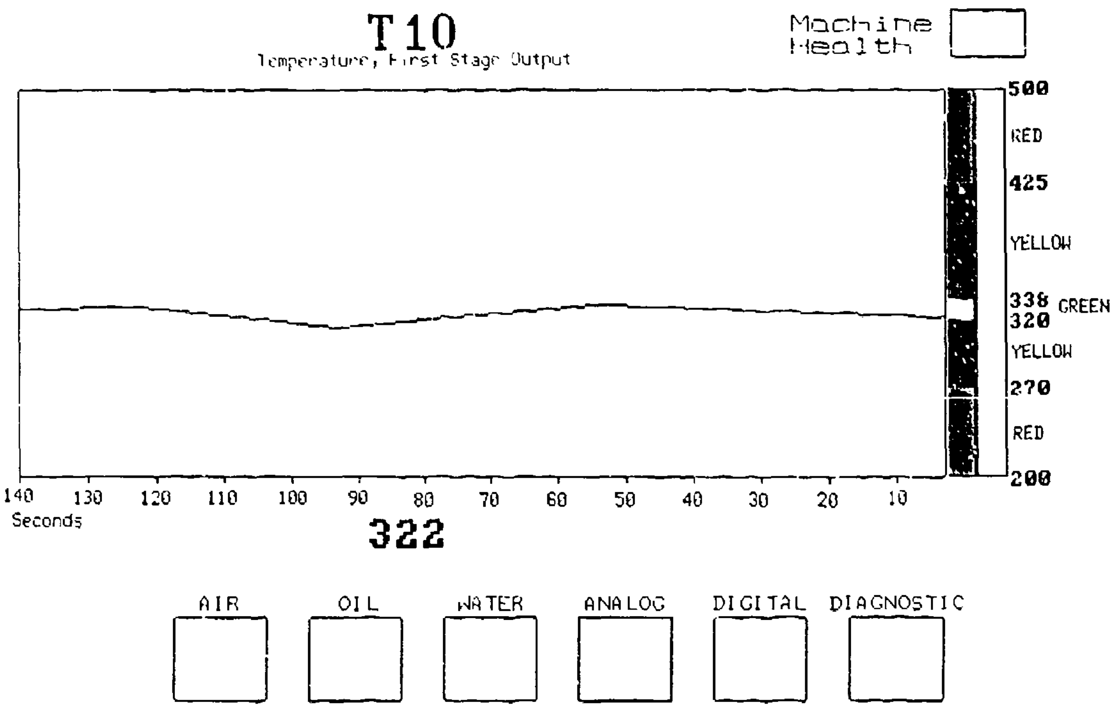

Fig. 7. Example data display screen.

The C program provides piecewise linear scaling of data for the ANALOG DISPLAY, and controls the color of the MACHINE HEALTH box and major screen boxes on each display. Future CBM systems will use an expert system rather than hard coded rules in order to support larger rule bases.

EXPERT SYSTEM PROGNOSIS

The final element in the CBM model is the prognosis capability. Prognosis projects future machine health based on current and past condition. The expert system software will be extended to provide prognosis. It will use a knowledge base developed for the machine along with a probabilistic model of the HPAC to provide predictions of future machine health. Probabilities will be assigned to these predictions to give the operator an indication of the degree of confidence with which the prediction is made. The development of probabilistic machine models are crucial in order to provide more than a limited prognosis capability.

Work is being done at Columbia University on the method of state space machinery models. Data collected from the machine will be used to establish normal and abnormal state spaces. Algorithms will be developed to construct a multidimensional state space model of the HPAC. Although beyond the scope of this paper, this method has the potential of providing sophisticated prognostics.

FUTURE PLANS

The plans for CBM are to expand the present system to include the extended diagnosis and the prognosis capabilities discussed. Work will continue on the integration of the process control and expert system software. CBM may be extended to other operating systems with greater multitasking capabilities and larger memory models in order to accomplish this.

CBM will use the knowledge gained in developing the diagnosis and prognosis features to expand and refine the HPAC sensor suite. Sensor technologies will be developed as necessary for the detection of machinery health problems. Finally, CBM will be continually refined and expanded to include other shipboard machineries.

CONCLUSION

The CBM demonstration model will provide the Navy with the vehicle to improve its maintenance procedures and reduce costs. The challenge is to integrate CBM into the naval shipboard environment by using the knowledge gained from this effort to generate the guidelines for future machinery development and ship system designs.

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